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AVALANCHE HAZARD ZONING IN VAIL, COLORADO: THE USE OF SCIENTIFIC INFORMATION IN THE IMPLEMENTATION OF HAZARD REDUCTION STRATEGIES

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ABSTRACT The inter-relationship between settlement pressures in the Town of Vail, Colorado and the hydrological and geophysical natural hazards of the upper Gore Creek Valley poses problems shared by other rapidly developing mountain towns in Colorado and other Rocky Mountain states. What is unique in Vail's case is that town government officials and some early developers sought expert scientific opinion on the identification and mapping of these natural hazards before such action was legally required. The scientific information was incorporated into hazard zoning ordinances. This paper examines with several case-studies how the municipality of Vail has used the expert scientific information in the implementation of its avalanche hazard zoning and how it has responded to land-use decisions in relation to the pressures of property development in those zones.

RÉSUMÉ *Zonage basé sur les dangers d'avalanche à Vail, Colorado: utilisation de données scientifiques pour mettre en oeuvre des stratégies de réduction des dangers.* La relation mutuelle entre les pressions d'affaissement dans la ville de Vail, Colorado, et les dangers hydrologiques et géophysiques naturels de la vallée supérieure de Gore Creek pose des problèmes qui se retrouvent dans d'autres villes de montagne en voie de développement rapide dans le Colorado et d'autres états des Montagnes Rocheuses. Néanmoins, Vail est unique du fait que le conseil municipal et un certain nombre de lotisseurs ont demandé conseil à des scientifiques au sujet de l'identification et de la localisation de ces dangers naturels bien avant que de telles démarches deviennent obligatoires. Les données scientifiques ont été incorporées dans les règles de zonage basées sur l'évaluation des dangers. Cette étude examine à l'aide de plusieurs études de cas la manière dont la municipalité de Vail a exploité l'information scientifique disponible pour mettre en oeuvre un zonage basé sur les dangers d'avalanche, et comment elle a répondu aux décisions concernant l'utilisation des terres en rapport avec les pressions du développement foncier dans ces zones.

ZUSAMMENFASSUNG *Lawinengefahrzonierung in Vail, Colorado: Nutzung von wissenschaftlicher Information bei Maßnahmen zur Gefahrenminderung.* Die Wechselbeziehung zwischen Besiedelungszwängen in der Gemeinde Vail, Colorado und den hydrologischen und geophysikalischen Naturgefahren im oberen Gore Creek Tal bringt Probleme mit sich, denen andere, schnell wachsende Berggemeinden in Colorado und in anderen Staaten der Rocky Mountains ebenfalls gegenüberstehen. Das Besondere im Fall Vail ist, daß die Gemeindeverwaltung und einige der ersten Planer wissenschaftlich fundierte Expertisen zur Erkennung und Kartierung dieser Naturgefahren einholten, noch bevor es gesetzlich gefordert war. Solche wissenschaftliche Information wurde dann auch in gesetzliche Verordnungen, die die Einteilung in Gefahrenzonen regeln, eingebracht. Diese Veröffentlichung untersucht anhand von Fallstudien wie die Gemeindeverwaltung Vail wissenschaftlich fundierte Information bei der Lawinengefahrzonierung angewendet hat, und welche Konsequenzen sich für Zonen ergaben, wenn Landnutzungsbeschlüsse unter Erschließungszwängen standen.

INTRODUCTION

Even before the passage of the State of Colorado natural hazard legislation (Colorado House Bill 1041, 1974), Vail's city management team realized the potential for increased risk from the avalanche hazard in the narrow, upper Gore Creek valley because of the rapidly expanding development in the area (Ives and Krebs, 1978). House Bill 1041 mandated local evaluation of natural hazard potential by county governments. In 1973, at the invitation of the Town of Vail city manager, Terrell Minger, an interdisciplinary team from the Institute of Arctic and Alpine Research (INSTAAR, 1974) at the University of Colorado began an intensive study of hydrologic and geologic hazards in the upper Gore Creek valley which included identification and mapping of avalanche and mud flow/debris flow hazard zones. The city government sought expert opinion for purposes of designing an adequate master plan for the existing townsite and the areas of expected annexation. These included areas east of the city with the greatest potential for avalanche occurrences (Figure 1).

Ground breaking for the new town and ski resort designed and built "overnight" by Vail Associates, Inc. began in the summer of 1962 (Dallas, 1969; Oaks and Gruenfeld, 1979). In the ten short years from 1962 to 1972 (the time of the management decision to elicit outside expert opinion) property development in Vail included structures that had been built in areas that were defined later as high

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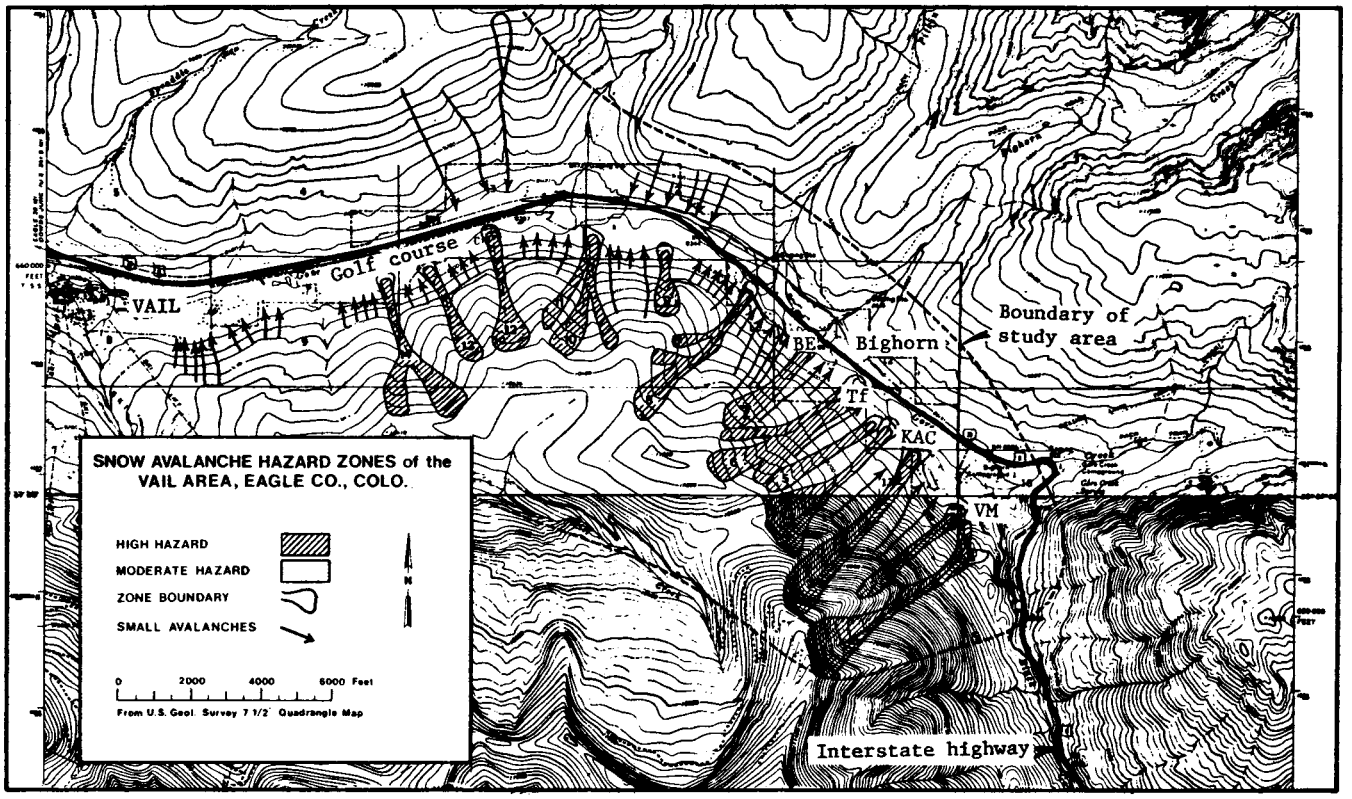

Figure 1. Map showing the avalanche zones in the Vail area of the upper Gore Creek valley. BE—Bighorn Estates, Tf—Timberfalls, KAC—King Arthur's Court, VM—Vail Meadows.

and moderate avalanche hazard zones by the INSTAAR (1974) study. The difficulties associated with the pre-existing, non-conforming structures in these zones have been an on-going problem in Vail and one which has not been addressed adequately to date. However, a more successful approach has been taken with respect to new construction and avalanche hazard zoning (Weber, 1976; Ives and Krebs, 1978; Oaks, 1983; Dexter, 1985). Since the enactment of Colorado House Bill 1041 and the adoption of avalanche hazard zoning guidelines and ordinances by the Town of Vail in 1978 (Town of Vail, Ordinances, Title 18 Zoning, Hazard Regulations, Chapter 18.69, Ordinance #12, 1978), strictly implemented policy on new construction includes the prohibition of new construction in high hazard areas (red zones). Zoning ordinances allow new construction in moderate hazard areas (blue zones) and in avalanche influence zones (AIZ) if site-specific studies indicate that adequate mitigating measures can be successfully undertaken to protect human life and property from potential avalanches.

However, there is a constant influx of development to this world-acclaimed resort area which is confined by the natural limiting features of the narrow Gore Creek valley. This has created constant pressure on the town government and has challenged the effectiveness of the hazard zoning ordinances in reducing risk. Some previous studies (Weber, 1976; Ives and Krebs, 1978; Oaks, 1983; Dexter, 1985) have detailed municipal decisions about land-use allocations and the avalanche hazard. A partial inventory of land-use decisions concerning the avalanche hazard up to the present is given in Table 1 as an example of the process used. Case studies are used to illustrate problems faced by the town with respect to the use of expert opinion concerning the geophysical aspects of the avalanche hazard in relation to economic, political, and social processes connected with development pressures and land-use decisions in avalanche hazard zones.

This study does not include the adjacent ski area, although it is important to note that after the ski season ends in mid-April the daily avalanche control measures are curtailed. Therefore, potential avalanche danger exists at several sites including the area below Chairlift 16 which borders on the centre of the Vail Village core area. Interestingly, this is also one of the debris flow hazard areas during spring and summer months identified by the State of Colorado Geological Survey (Junge, personal communication). Despite the fact that the INSTAAR (1974) project also clearly defined the mud flow hazard in Vail, town management had little success in eliciting the same strong public reaction to its potential for losses that the avalanche hazard evoked (Minger, personal communication; Ives, personal communication). Yet, it is the mud flows, not avalanches, that have caused the most damage in the town to date. In the spring months of 1984 and 1985, several large mud flows blocked roads (including Interstate Highway 70) and necessitated the evacuation, and later abandonment, of sev-

Table I
Vail avalanche zone data—extracts[1]

Property description	Structure type	Date (1)	Hazard Red/Blue/Influence zones	Site study Yes/No	Comments
Vail Meadows					
Lot 21	Water tank	Pre-1975	R	Y	Gore Valley Water District.
	Residential	1977	R/B	N	Placement mitigation.
	Garage	1982			LeRoy garage issue.
Lot 22	None		R	Y	Rau property and study.
Lot 23	Residential	1976	R/B/I	N	Placement may have mitigated.
Lot 24	Residential	1980	R/B/I	Y	Placement mitigation.
Lot 25	Residential	1981	B/I	Y	Structural design mitigation.
Lot 26	Residential	1982	B	Y	Structural design mitigation.
Lot 28	Residential	1978	B/N	N	Placement mitigation.
Lot 30	Residential	Pre-1975	B/I/N	N	Placement mitigation.
Lot 31	Residential	1980	I/N	N	Placement mitigation.
Bighorn, 5th Addition					
Lot 1	Residential	1982	R/B	Y	Structural design mitigation.
Lot 2	Residential	Pre-1975	B/N	Y	Defence structure mitigation.
Lot 6	Residential	Pre-1975	I	N	All of the following lots were
Lot 7	Residential	Pre-1975	I	N	annexed by Vail around 1975,
Lot 8	Undeveloped		I	N	and are thus assumed to be
Lot 9	Residential	Pre-1975	I	N	pre-1975 structures.
King Arthur's Court	Residential	1975	R/B	Y	Financial backing withdrawn, structures removed.
Bighorn Townhouses	Residential	Pre-1975	R/B	Y	Pre-existing in red zone.
Vail Racquet Club	Resort/ Residential	Pre-1975	B/Y	Y	Placement and structural design mitigation.
Courtside Townhouses	Residential	Post-1976	R/B/N	Y	Placement mitigation.
Timberfalls Condo	Residential	Pre-1975	R/B/N	Y	Placement and defence structure mitigation.

[1]A complete inventory of land-use decisions with respect to the avalanche hazard in Vail is available from the authors.

eral homes in the West Vail and intermountain regions west of the city. The State of Colorado Geological Survey is currently monitoring the geological hazard in those areas (Rogers, personal communication). After commissioning several scientific studies (Mears, 1984; Schmueser and Associates, 1984), the Town of Vail adopted a revised section concerning mud flow/debris flow and rock fall hazard to its hazard zoning ordinance in 1985 (Town of Vail, Ordinances, Title 18 Zoning, Hazard Regulations, Chapter 18.69, Ordinance #5, 1985). Provisions were made by this Sensitive Areas Ordinance to restrict building in high hazard zones but mitigating studies or measures were not required in moderate hazard zones. These restrictions differ from the avalanche hazard ordinance because when the zoning was proposed over 200 pre-existing structures already existed in the high and moderate hazard area. It was therefore more difficult to implement this section of the zoning ordinance because, unlike the avalanche section previously implemented at the subdivision level, this section of the ordinance is being implemented much later at the level of each individual building lot. Furthermore, pressure placed on the town government by real estate and construction development interests resulted in the enactment of a less strict version of the ordinance than was initially proposed.

SCIENTIFIC STUDIES CONCERNING THE AVALANCHE HAZARD IN THE UPPER GORE CREEK VALLEY

In 1973 the INSTAAR team began hydrologic and geologic hazards research in the upper Gore Creek valley and applied techniques they had developed and used in other Colorado mountain towns to the Vail area (Ives *et al.*, 1972; Bovis and Mears, 1976; Burrows and Burrows, 1976; Ives *et al.*, 1976; Ives and Bovis, 1978). The early mapping done by the INSTAAR team and by Mears (1975, 1976), who was also a member of the original INSTAAR group, proved to be accurate in forecasting the 21 April 1980 avalanche in Bighorn (Junge, 1982). This wet snow avalanche from chute #7 deposited 15,000–20,000 tons of snow in its runout zone near two East Vail homes (Figures 2 and 3).

A hazard zone classification based on the established Swiss model (Frutiger, 1970) was adopted into Town of

Vail ordinances in 1978 (Town of Vail, Ordinances, Hazard Regulation Chapter 18.69). Those zones included:

Red Zone—high potential avalanche hazard zone
impact pressures > 600 lbs/sq. ft.[1]
return periods < 25 years
residential construction not allowed

Blue Zone—moderate potential avalanche hazard zone
impact pressures < 600 lbs/sq. ft.[1]
return periods 25 to 100 years
residential construction allowed if the hazard is mitigated

AIZ Zone—avalanche influence zones
residential construction is allowed with site specific study (added to the 1978 version of the code)

Some notable differences exist between the Vail Classifications and the Swiss model, the most significant of which is the reduction of the recurrence interval from 300 to 100 years. Although the Vail record does not extend back into time for that period, the length of snowfall record from nearby stations is sufficient to estimate the 100-year return period (Borland, 1973; Mears, 1975).

The colour-coded zones were considered for incorporation in the Town of Vail master plan as early as 1975, but the avalanche influence zone classification (AIZ) was added in 1978 after further work had been completed by Mears (1976) and LaChapelle (1976). The zones were identified primarily on the basis of vegetation studies (Krebs, 1973; Mears, 1975; Burrows and Burrows, 1976) and on Swiss avalanche dynamics calculations adapted from Voellmy (1955). Since the documented historic record at Vail is short, long-term documentary sources such as those used for investigations by INSTAAR specialists in other Colorado mountain towns (Ives *et al.*, 1976; Armstrong, 1976, 1977) were not available. Some interviews were conducted by the INSTAAR team. Subsequent interviews were conducted by Forest Service personnel (Gregg, personal communication), by local newspaper reporters from *The Vail Trail,* and by Oaks (1978–1983, unpublished interviews) with ranchers, farmers, and miners who used the area, and there were discussions with the founders of Vail. Some of these interviews did corroborate the occurrence of large snow and debris flow events which crossed the Gore Creek valley floor in the 1940s and 1950s, but none could provide

Figure 2. The 21 April 1980 wet snow avalanche (chute 7 on Figure 1) deposited 15,000–20,000 tons of snow in the runout zone. Photograph courtesy of the State of Colorado Geological Survey.

[1]Approx. 2,930 kg per m².

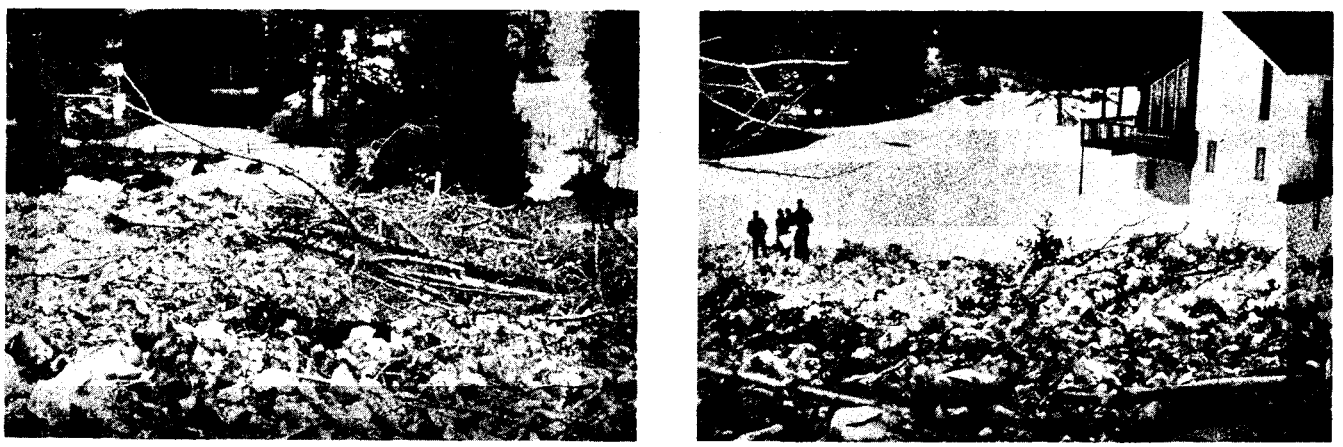

Figure 3. The 21 April 1980 avalanche deposited debris within 16 m of the house on Lot 7 (left) and within 9 m of the house on Lot 16 (right) of the Bighorn Estates. Photographs courtesy of the State of Colorado Geological Survey.

the exact dates of the instances. There is some dispute concerning the reliability of these reports, and they have been debated by members of the original INSTAAR team (Carrera-Martinelli, written correspondence). Because the ranchers, farmers, and miners did not witness the occurrence of the events, but rather saw the remains of avalanches and the debris in the spring as they entered the valley for seasonal use, there is question as to the validity of their reports. However, during the spring of 1973, activity was recorded on all the major avalanche paths.

The avalanche hazard mapping studies including INSTAAR (1974), Mears (1975), and LaChappelle (1976) were adopted by the municipality (Town of Vail, Ordinances, Title 18 Zoning, Hazard Regulations, Chapter 18.69) as were site-specific studies for developments and individual homesites in the area. Together these studies represent a significant base of scientific opinion supported by legal authority. The implementation of the hazard zone plan put approximately 40 properties (Weber, 1976; Ives and Krebs, 1978) in the pre-existing, non-conforming status. In addition, the pressure of new development, especially after 1977 when property values quadrupled (Vail Associates, Inc. Real Estate Department, personal communication), tested the hazard zoning and ordinance enforcement in Vail. An overview of the municipal response to development decisions is shown in Table 1 and represents some of the decisions from 1975 to 1984 with respect to avalanche hazard zoning.

CASE STUDIES: THE USE OF SCIENTIFIC INFORMATION IN THE IMPLEMENTATION OF AVALANCHE HAZARD REDUCTION STRATEGIES

Several cases in the Vail Meadows area serve to demonstrate how the Town of Vail has continued to uphold the avalanche hazard zoning ordinances in terms of new construction. The area is also indicative of problems that have occurred with respect to pre-existing, non-conforming structures. This area currently marks the eastern edge of development in Vail and occupies the narrowest portion of the Gore Creek valley within the town boundaries. The runout zone of the Vail Meadows Avalanche path (path #10) affects Lots 21-26 and Lots 28-30. The avalanche influence zone (AIZ) also affects Lots 30 and 31. In addition to direct impact pressure considerations from events in this path, there is the added problem of the 500,000-gallon (almost 2,000 kl) Gore Valley Water District tank (Figure 4) located well within the red zone about 150 m upslope from residences on Snowshoe Drive.

The avalanche zoning ordinance in this part of the upper Gore Creek valley has been tested by two interesting petitions: the LeRoy case on Lot 21 and the Rau case on Lot 22. Each case concerns the use of scientific opinion with respect to implementation of the hazard reduction zoning ordinances and problems associated with liability.

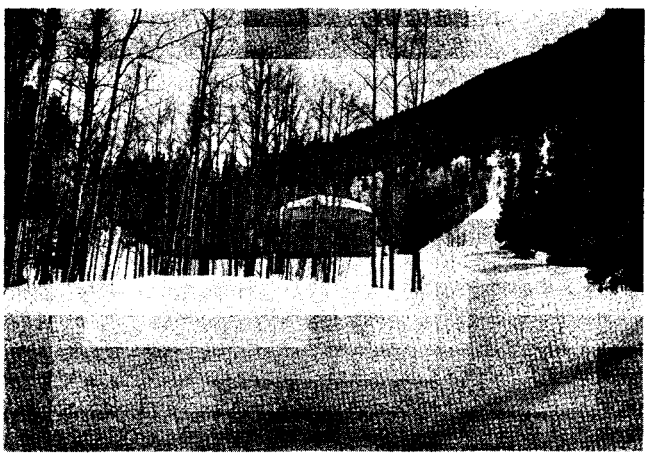

Figure 4. This water tank belonging to the Gore Creek Water District is located within the high hazard (red) zone of the Vail Meadows avalanche path.

The LeRoy Case

The LeRoy case is a good example of management problems associated with the delicate balancing act between individual property owner rights and the economic and political realities of policy decisions concerning land use for the common good. It also demonstrates the strict observance of avalanche hazard zoning by the Town of Vail planning and development staff, the planning commission members, and members of the town council. It shows the value placed on expert scientific opinion by those officials in the Vail city government.

Tom LeRoy has been familiar with mountain environments for many years. As an expert ski racer and freestyle skier, LeRoy was responsible for the success of freestyle and exhibition skiing in Vail in the 1970s, and in the process became an early promoter for Vail. He purchased Lot 21 in Vail Meadows before the area was designated as an avalanche hazard zone. About one-half of the lot is affected by the high (red) and moderate hazard (blue) avalanche zones (Figure 5). In 1977, LeRoy applied for, and was granted, a setback variance in order to build a 1,528 sq. ft. (about 142 sq. m) single-family dwelling outside of the high hazard zone in an avalanche influence zone (AIZ). By doing so the town felt it allowed "reasonable development" because of "development limitations" faced by LeRoy (Town of Vail, Planning and Environmental Commission, Minutes, 11 May 1982).

In 1982, LeRoy requested another variance (side property line setback) to construct a garage in a northwestern section of his lot which lay in the high hazard zone. He requested this because of the "steep and particularly difficult" access to his house which was "plagued by the winds and drifting snow." He requested the variance toward Lot 22 which was vacant and unbuildable because it lay entirely in the high hazard zone. LeRoy stated that the front portion of his property, which he had been using for five years as an access, was in the high hazard zone. In his comments entitled "Addressing the Hazard Zone," he stated that he

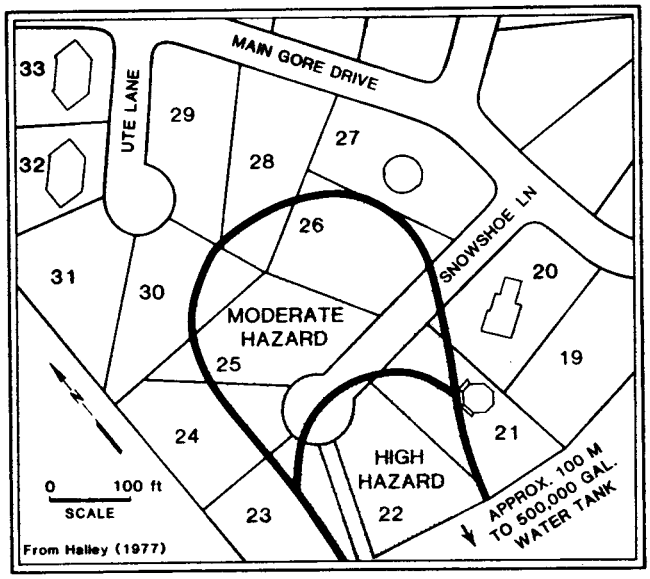

FIGURE 5. Plan of building lots in Vail Meadows. Lot 22 lies entirely within the high hazard zone and a house of Lot 21 has been built at the edge of the avalanche path.

and his family were "aware of the potential loss" and were "willing to assume all costs and responsibilities of such an event". He added he was "willing to share the same responsibility that the Town of Vail has with allowing the water tank of 500,000 gallons to be left unprotected in a high hazard avalanche zone". LeRoy concluded "they are both uninhabited *structures*". LeRoy requested that section 18.69.040 of the hazard zoning ordinance (Town of Vail, Ordinances, Zoning Title 18, Hazard Zoning, Chapter 18.69) be amended. The hazard regulation states that "no structure shall be built in any floodplain or red [high] avalanche area . . ." The term "structure" as used in that section does not include recreational structures that are intended for seasonal use, not including residential use. LeRoy wanted to amend the code to include "uninhabited structures such as garages, water tanks, and mechanical pump stations, but not including inhabited residential use".

The Department of Community Development disagreed with amending the code or granting a variance and stated that "to allow construction of other than summer-oriented, recreational uses in a high hazard zone would create a far reaching and dangerous precedent". The staff also recommended that the garage be built "on the other side of Lot 21 in the moderate hazard zone *with the necessary mitigating measures*" (Letters from LeRoy, 25 and 26 April 1982, Memorandum to Planning and Environmental Commission from Department of Community Development, 17 May 1982). In making its recommendations, the staff cited a letter from Arthur Mears that stated "The frequency of avalanches in the high hazard zone is considered to be too great to permit residential construction regardless of the details of the structural design. Personally, I feel it is very important for the Town of Vail to ensure that no residential construction be done in the high hazard zone" (Letter to Jim Rubin, Director of the Department of Community Development from Arthur I. Mears, P.E., 9 March 1977).

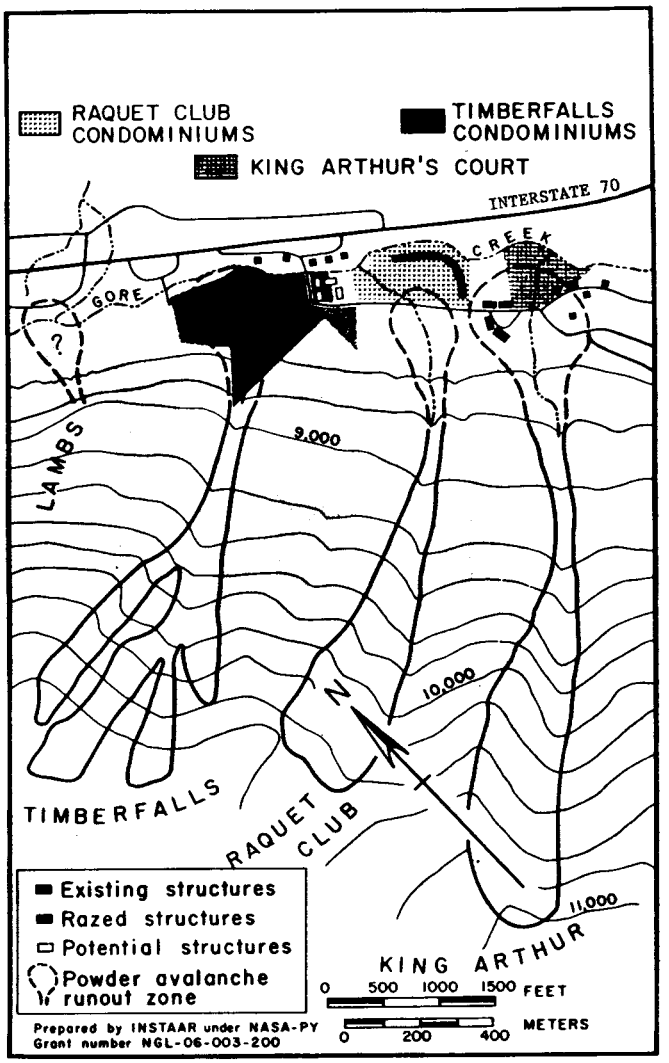

FIGURE 6. The King Arthur's Court development. Several pre-existing structures were razed as a result of the hazard mapping project and much of the property has now been developed as a park.

Interestingly, all of LeRoy's neighbours recommended that the variance be granted. One, a professional skier and Vail Mountain Rescue team member, urged that the town "allow him [LeRoy] to build this garage subject to his taking all responsibility for the possible damage or destruction to the garage due to an avalanche thus relinquishing any claims against the Town of Vail" (Letter to Zoning and Planning Board from Jim Colburn, 22 May 1982).

In another memorandum, and at a subsequent public hearing, LeRoy stated "it is totally unfair that as a property owner I should be denied the right to erect my own garage on my own property taking all responsibility in writing". LeRoy again brought up the question of the pre-existing, non-conforming water tank (Figure 4) which, like his property, lay in the Vail Meadows avalanche high hazard zone (Minutes from Public Hearing, 24 May 1982).

Peter Patten, Director of Community Development, felt the issue was not the water tank or the LeRoy lot, but the amendment of the zoning code. He stated that if the code

were amended as proposed by LeRoy, people could build decks or storage areas and would create activity and additional structures that would become debris in the event of an avalanche in the high hazard zones. LeRoy was instructed to apply for a variance and not an amendment of the code (Minutes from Public Hearing, 24 May 1982).

Within the next five weeks the Department of Community Development recommended denial of the variance on the basis that "human activity of any sort should be discouraged in the red avalanche zones during the winter" (Memorandum to Planning and Environmental Commission from Department of Community Development, 10 June 1982). A few days later the Planning and Environmental Commission made a decision based on the Mears opinion. The commission conceded that they were not experts and were therefore relying on expert scientific opinion that no residential construction be allowed in the high avalanche hazard zones. The commission voted 4-0 against the variance (Planning and Environmental Commission, Minutes, 14 June 1982). Later that year the commission approved a setback variance for the LeRoy property which allowed the building of the garage into the hillside of the southwest corner of the lot or in the northwest corner in the moderate hazard zone (Planning and Environmental Commission, Minutes, 11 October 1982).

The Rau Case

Another case in the same subdivision evoked similar action by the Planning and Environmental Commission. George Rau, a long-time Vail resident, ski coach, and the owner of Lot 22, wanted to put a structure on that lot which is entirely in the high (red) avalanche zone (Figure 5). The structure was to be designed along the lines of a snowshed of the type that is used to protect highways and railways from avalanches. The Planning and Environmental Commission denied the request, again basing its decision on the information from scientists that this property was located within the red zone. The decision was also upheld by the view that regardless of how well the structure was designed, persons outside the structure would be unduly exposed to the avalanche hazard (Memorandum from Planning and Environmental Commission to the Department of Community Development).

THE LIABILITY ISSUE

These cases also serve to illustrate the complex social, economic, and political issues of personal property rights, hazard mitigation, and liability. LeRoy was willing to state in writing that he and his family would accept full responsibility for personal loss. However, what would happen in terms of liability if the LeRoy garage were swept by an avalanche to an adjoining property? Even if the losses were confined to the LeRoy family and their property, to whom would liability be assigned in the event a suit was filed by the LeRoys against the city?

Although the recently passed Colorado Tort reform (Colorado Revised Statutes, Title 13, Courts and Court Procedure, Chapters 104-116, 1986) favours Colorado municipalities in this respect, case law is not as clear on the issue of liability. This viewpoint is commonly shared in the legal community. Alaska statutes suggest municipal immunity from tort liability in relation to land-use planning functions of municipalities, but do not completely bar access to the courts, as state or private entities may be sued in connection with claims concerning losses from municipal actions (Alaska Statutes, Title 9, Code of Civil Procedure, Chapter 65). Washington statutes do not insure governmental immunity (Washington Statutes, Title 17, Chapter 164). Although Utah has a governmental immunity act (Utah Code, Title 63, Governmental Immunity Act, Chapter 30), if scientific evidence regarding a hazard is well known then the immunity may be waived (State of Utah, Attorney General's Office, personal communication).

The question of liability ensures that the Town of Vail government and many other local and state governments will move cautiously. In fact, some municipalities are hesitant to write ordinances dealing with hazard zones and building restrictions because of the issue of liability (Salt Lake City planning officials, personal communication). Anchorage, Alaska considered the adoption of an "Interpretation and Disclaimer of Liability" into its avalanche hazard code. The disclaimer proposed that regulations concerning land use in avalanche hazard zones should be "considered as minimum requirements" and "liberally construed in favor of the governing body". The proposed regulation recommendations also included a "warning and liability disclaimer" which states: "The degree of avalanche protection required by this chapter is reasonable and is based on scientific and engineering considerations. Larger avalanches can and will occur on rare occasions. This chapter does not imply that avalanches will not occur outside the limits of the designated hazard zones" (Anchorage Hazard Ordinance of 1985, Amendment to Title 21, Municipal Planning and Zoning Code). Nevertheless, because of uncertainty over the liability issue, as well as pressure from real estate and development interests, the Municipality of Anchorage tabled and then withdrew this proposed ordinance after it was defeated during the second reading (Municipality of Anchorage, Department of Community Planning, personal communication). Currently, the municipality operates under existing discretionary authority and internal administrative procedures on this issue (Municipality of Anchorage, Assembly Memorandum, AIM 323-86, 1986).

MUNICIPAL PROBLEMS—ADDITIONAL ADMINISTRATION FOR RISK REDUCTION

In reviewing the Vail case of pre-existing, non-conforming structures in avalanche hazard zones, Greenstein (1982) stated that "hazard studies have *created* problems for the town." While former town manager, Terrell Minger, agrees

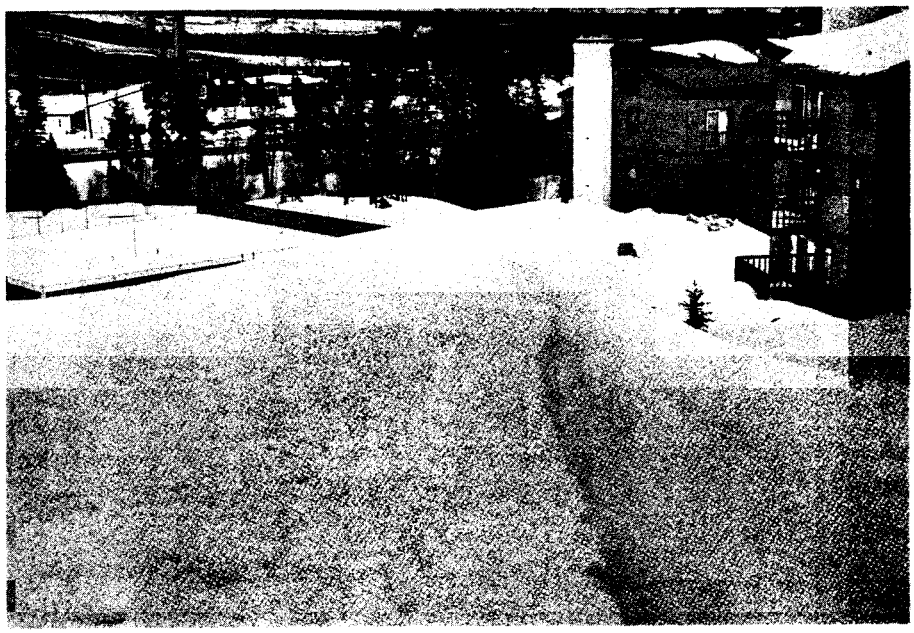

Figure 7. A development project in the Timberfalls avalanche zone. A large earthen berm defence structure was designed to mitigate the hazard.

that avalanche zoning has created management and administrative problems in relation to the pre-existing structures, he also maintains that the zoning regulations have been very influential in lowering the potential impact of avalanches on new developments in Vail. In addition, he submits that the lessons learned at Vail may be valuable in the planning of new developments and towns elsewhere (Minger, personal communication).

This certainly has been the case for new developments in the Vail area with respect to avalanche hazard. All special improvement districts and new developments are required to submit an extensive geological hazards analysis of the entire site to the Town of Vail before development begins. Areas of high hazard potential are designated as open space. This was the case with the Glen Lyon subdivision in West Vail (THK Associates, 1977) and other subdivisions developed in the upper Gore Creek valley after the Town of Vail had adopted this section of its hazard zoning regulations (Town of Vail, Ordinances, Title 18 Zoning, Hazard Chapter 18.69). The Sunburst Development donated a large tract of its property in the high avalanche hazard zone to the Town of Vail as open space (Town of Vail, Department of Community Development, personal communication).

In another case, that of King Arthur's Court, large construction projects that were already underway when the code was adopted were also affected by the hazard zoning. The original hazard mapping completed by INSTAAR (1974) and by Mears (1975, 1976) identified part of the King Arthur's Court project in the high (red) avalanche hazard zone at the base of the avalanche path (Figure 6). Economic pressure was exerted on the developer because adjustments in the project with respect to the hazard were not made. Construction loans were withdrawn and the developer was forced ultimately into foreclosure on the project. The site was condemned by the Town of Vail and purchased several years later. Eventually it was developed as a park by the town government.

Other early developers reacted more favourably to the avalanche hazard mapping. The developers of Timberfalls commissioned a study of the avalanche hazard on their property (Borland, 1973) which is located adjacent to Timberfalls Path #6. They also retained Hans Frutiger, the renowned Swiss avalanche expert from the Swiss Federal Institute for Snow and Avalanche Research, to design an earthen berm defence at the western edge of their development (Figure 7).

MUNICIPAL PROBLEMS—CONFLICTING SCIENTIFIC OPINION AND POLICY DECISIONS

The Gore Valley Water Tank Case

As mentioned in the LeRoy case, the Gore Valley Water District tank, which sits within the high hazard zone of the Vail Meadows avalanche path, is a pre-existing, non-conforming structure. The INSTAAR study (1974), Mears (1976), LaChapelle (1976), and Halley (1977) all identified the Gore Valley Water District's 500,000-gallon water tank as lying squarely in the Vail Meadows avalanche path (Figure 4). Mears (1976) stated that small and large avalanches alike would reach the tank site. LaChapelle (1976) observed that "sooner or later it will be struck by an avalanche and quite possibly by a large and destructive one". LaChapelle cited a case where a "moderate-size avalanche (far smaller than the Vail Meadows path) struck a 20,000-gallon water tank serving a mountain home development. The combined avalanche and water completely demolished

a house on a shallow slope below, causing one fatality". LaChapelle recommended a diversionary structure be built or that the tank be moved to a safe location.

The Gore Valley Water District submitted results of a study completed for them on the Vail Meadows avalanche (Halley, 1977) to the town council. The conclusions of that study stated that the tank, if kept 80 percent full, could completely resist a design avalanche (100-year or 1 percent chance of occurring in any year). The Gore Valley Water District board stated that the tank would be kept at that level as an adequate means of solving the problem. The alternative of building a diversionary structure was estimated at a cost of $25,000 and the cost of moving the tank was estimated at approximately $100,000 (Memorandum to Gore Valley Water District Board of Directors from James P. Collins, 23 June 1977). The information was presented by city council member Jim Ruder (also on the Gore Valley Water District Board) at a town council meeting. He reported that the study had been made public to assure area residents that the tank did not pose a danger to the structures below (Town of Vail, Town Council Minutes, 5 July 1977). Despite the warning by LaChapelle (1976) that the storage tank could at worst "present a severe hazard to the areas below if an avalanche stressed hard enough to cause rupture" or at least cause the "loss of domestic water service for East Vail for months", the town council chose to accept the Halley report.

This case represents a distinct problem facing policy makers at various levels of government—what course of action should be taken when the opinions of scientific experts do not agree. The former city manager of the Town of Vail explained the town's reaction to the situation at that time (Minger, personal communication). The Vail town government, characterized by its elicitation and reliance on scientific judgement for policy decisions concerning hazard zoning, was placed in a particularly difficult situation in this instance as the opinion and advice of experts varied widely. In terms of costs and benefits, the decision was made to accept the Halley conclusions. That decision also was made because of what the town management perceived as a lack of consensus on the part of the scientific experts and a level of uncertainty in the scientific conclusions that did not justify the costs of moving the tank or providing a protective avalanche structure above the tank.

This decision by the town may be criticized by maintaining that a greater number of experts recommended diversions or removal instead of the solution to keep the tank 80 percent full and allow it to remain in the high hazard zone. However, the need by policy makers for more definitive scientific information from the experts should be recognized. Government officials want to know answers to questions of magnitude and probability. For example, the management officials and the town council wanted to know "What are the exact sizes of avalanches which might dislodge the water tank?" and "What are the probabilities for occurrence of those avalanche types?" The perceived lack of consensus on the part of experts and the level of uncertainty in scientific conclusions makes policy decisions for municipal officials and informed city council members (as was the case in Vail) extremely difficult.

IMPLEMENTATION—THE IMPORTANCE OF SOCIAL, POLITICAL, AND ECONOMIC PROCESSES AS WELL AS SCIENTIFIC EVIDENCE

These case studies show that implementation of hazard reduction measures is as much a function of political, economic, or social processes as it is of sophisticated scientific knowledge about the hydrologic or geophysical events (Hewitt, 1983). It also points to a fundamental, unsolved problem that exists between the scientific research community and policy makers concerning scientific uncertainty and implementation of hazard reduction strategies (Climate Impact Networkshop, 1985; Workshop on Earthquake Hazards Along the Wasatch Front, Utah, 1986).

Despite this recognized, but unsolved problem (Szanton, 1981), scientific avalanche hazard analyses in the Vail area have been valuable in reducing potential losses. Certainly, if the hazard evaluation and mapping had not been accomplished or had been ignored by the city of Vail, the risk from avalanches would be much greater than it is at present. The site-specific studies incorporated into the town ordinances along with the INSTAAR (1974), Mears (1975, 1976), and LaChapelle (1976) studies have been vital to the implementation of the hazard zoning ordinances applicable to new construction.

Besides the scientific process, the political process has also contributed to hazard mitigation in Vail. The successful implementation of these hazard reduction ordinances which were based upon expert scientific information *have been enforced* through the political process of review and site inspection carried out by the municipal government. This has been accomplished despite the economic and social pressures for development in the Vail area. As illustrated in the cases discussed, new construction has been denied categorically in the high (red) avalanche hazard zones and the original zoning has remained intact. In addition, legally required site-specific studies in the moderate (blue) avalanche hazard zones have helped mitigate possible losses in those areas through the use of placement mitigation, structural orientation, structural design modification, and through the use of defensive structures (Figure 8). In the avalanche influence zones (AIZ), where the town government has the option of requiring site-specific studies, it has uniformly exercised that option.

There have been some problems created by construction of mitigating structures that would shield certain properties from the avalanche hazard while redirecting avalanche flows to adjacent properties. The Shannon case (Bighorn Second Filing, Lot 11) serves as an example. This case illustrates, in addition, the importance of mapping of avalanche hazard zones at both regional scales (1:24,000) and at larger scales of 1" = 1,000 ft. (1:12,000) as required by the Department of Community Development to assess the hazard in relation to the total path characteristics and

Figure 8. Hazard reduction techniques include use of land for seasonal recreation such as tennis courts (left) and structural design such as the splitting wedge defence of the Vail Racquet Club (right).

the site-specific criteria. Some site-specific studies have alerted adjacent property owners to the avalanche hazard. This was the case when the King Arthur Court Avalanche study (Halley, 1975) identified an adjacent site—Bighorn Subdivision, Block 2, Lot 1—in the moderate avalanche hazard zone. A retaining wall was constructed to deflect an avalanche from that site.

The record of success in reducing the avalanche hazards is not as clear in the avalanche influence zones (AIZ). This is true with respect to the potential loss of life and property in the pre-existing, non-conforming structures. The 21 April 1980 avalanche showed the accuracy of the mapping by INSTAAR (1974) and Mears (1975, 1976), yet pre-existing, non-conforming structures in the Bighorn Subdivision have not been retrofitted structurally or protected with defence structures. While this is not required by law, there is potential for damage in the East Vail and Bighorn areas. The pre-existing, non-conforming Bighorn Townhouses are one example (Figure 9).

The uncertainty of the effects of avalanches in the AIZ zones also have contributed to another political and economic problem for the Town of Vail. A currently debated issue concerns who should pay for the site-specific studies and how many studies should be required. At present, property owners pay the expense of these studies. Department of Community Development officials would like to have the work done by consultants of their choice to insure the quality of the site investigations. For example, they would like to retain avalanche experts for the avalanche site studies and experts in geologic fields for other geologic hazard evaluations. They propose that the cost of the required studies be absorbed by the city. Others on the Vail management team are against this approach, and the issue is still subject to debate.

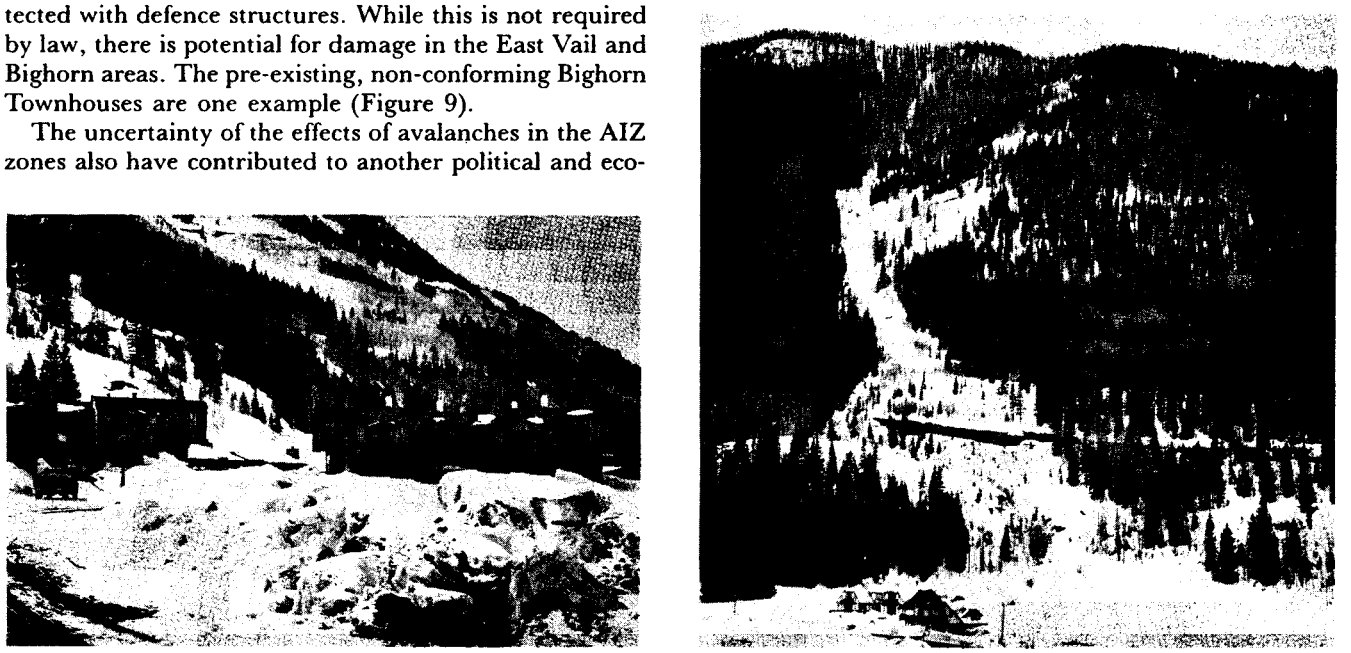

Figure 9. The Bighorn townhouses (left) are located in the high hazard zone of the King Arthur avalanche path (right). This project was developed before zoning regulations were implemented and no defence structures have been added.

CONCLUSIONS

The record of avalanche hazard mitigation in the Town of Vail has been successful for two primary reasons. First, the management team under Town Manager Terrell Minger sought expert scientific opinion regarding the identification and mapping of the avalanche hazard zones in 1972, at an early stage of Vail's development and before there were large numbers of pre-existing structures. The information obtained was incorporated into the comprehensive plan by the adoption of a hazard zoning ordinance. Second, the success of avalanche hazard reduction in the Town of Vail has been due to a commitment by subsequent municipal officials to the continued implementation of the hazard zoning ordinances. In many areas of the United States adequate municipal codes have been enacted, but are not enforced. In the case of Vail, town staff and officials enforce the codes routinely through a diligent site inspection and review process. Therefore, the reduction of avalanche hazard in the upper Gore Creek valley has occurred because of a combination of scientific studies about the geophysical processes coupled with successful implementation dependent on the political and social processes in the town.

Although decision-making problems for the town have occurred in some cases due to conflicting expert scientific opinion and, perhaps, to the very existence of the codes which create administrative problems, the avalanche hazard has been reduced dramatically because of the well-implemented, scientific-based zoning ordinances that were enacted before 1977 when Vail began to witness phenomenal growth. There are still risks associated with pre-existing, non-conforming structures as well as uncertainty over liability issues. These problems and issues have yet to be dealt with effectively at a local, state, or federal level. In terms of avalanche hazard reduction in the Town of Vail, the greatest challenge may be the continued implementation of the hazard zoning ordinances in the face of economic development pressures. Another challenge will be the formulation of hazard reduction strategies for geologic hazards such as mud flow and rock fall that the town has not considered with the same intensity as the avalanche hazard.

The interrelationship of both geophysical and social systems is responsible for the success or failure of hazard reduction. Implementation of hazard reduction strategies, in the form of zoning ordinances, is based not only on the quality of the scientific information that may be incorporated into zoning or even the political mandate to enforce such codes, but upon the ongoing social and economic circumstances as well.

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